US009172870B2

(12) **United States Patent**
Wu

(10) **Patent No.: US 9,172,870 B2**
(45) **Date of Patent: Oct. 27, 2015**

(54) **REAL-TIME IMAGE PROCESSING METHOD AND DEVICE ENHANCING THE RESOLUTION OF SUCCESSIVE IMAGES**

(71) Applicant: **VIVOTEK INC.**, New Taipei (TW)

(72) Inventor: **Jen-Chih Wu**, New Taipei (TW)

(73) Assignee: **VIVOTEK INC.**, New Taipei (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/255,603**

(22) Filed: **Apr. 17, 2014**

(65) **Prior Publication Data**

US 2014/0368682 A1 Dec. 18, 2014

(30) **Foreign Application Priority Data**

Jun. 14, 2013 (TW) ..... 102121252 A

(51) **Int. Cl.**
H04N 5/232 (2006.01)

(52) **U.S. Cl.**
CPC ***H04N 5/23232*** (2013.01)

(58) **Field of Classification Search**
CPC H04N 5/23232; G06T 3/4007; G06T 3/4038; G06T 3/403; G06T 11/60
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,239,428	B2 *	7/2007	Solecki	358/3.01
7,352,919	B2 *	4/2008	Zhou et al.	382/299
2007/0098301	A1 *	5/2007	Rengakuji et al.	382/300
2009/0238535	A1 *	9/2009	Robertson et al.	386/37
2014/0072242	A1 *	3/2014	Wei et al.	382/299

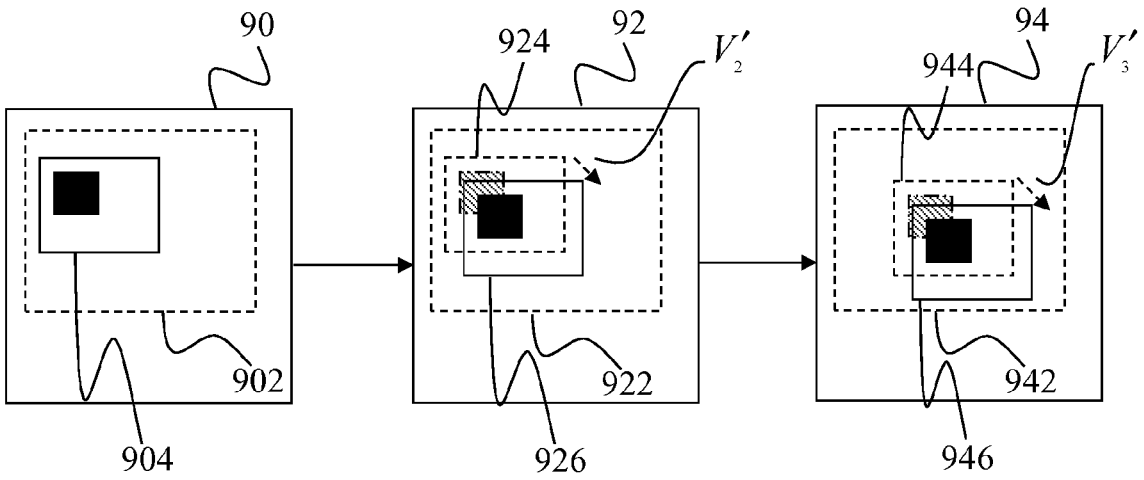
* cited by examiner

Primary Examiner — Luong T Nguyen
(74) *Attorney, Agent, or Firm* — Locke Lord LLP; Tim Tingkang Xia, Esq.

(57) **ABSTRACT**

Disclosed herein are a method and a device of real-time image processing. The method comprises capturing three images, enhancing a resolution of the images to obtain for each image a high-resolution image (HRI), obtaining two displacement vectors using the HRIs, obtaining a superimposed HRI based on the HRIs and the displacement vectors, obtaining a compensatory vector based on the displacement vectors, and generating a super-resolution image based on the superimposed HRI and the compensatory vector.

12 Claims, 5 Drawing Sheets



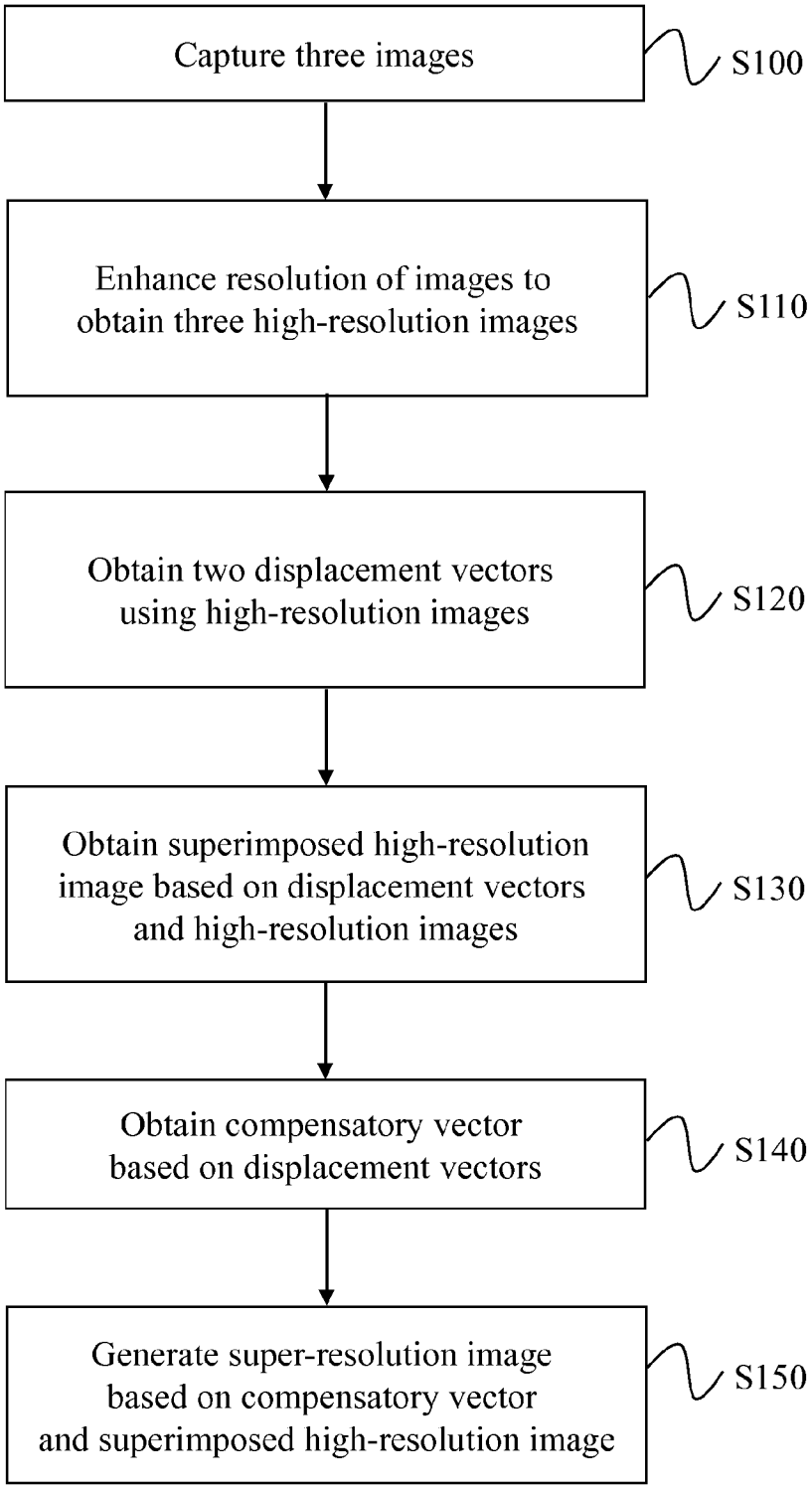

Capture three images
S100
Enhance resolution of images to obtain three high-resolution images
S110
Obtain two displacement vectors using high-resolution images
S120
Obtain superimposed high-resolution image based on displacement vectors and high-resolution images
S130
Obtain compensatory vector based on displacement vectors
S140
Generate super-resolution image based on compensatory vector and superimposed high-resolution image
S150

FIG. 1

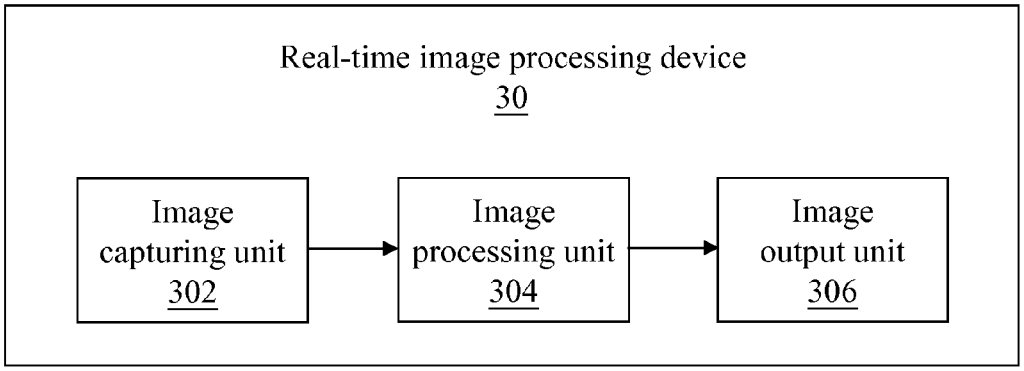

Real-time image processing device
30
Image capturing unit
302
Image processing unit
304
Image output unit
306

FIG. 2

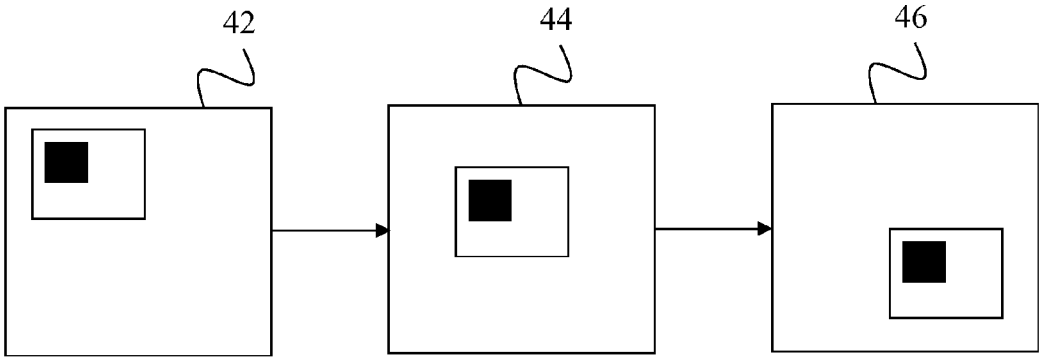

42
44
46

FIG. 3

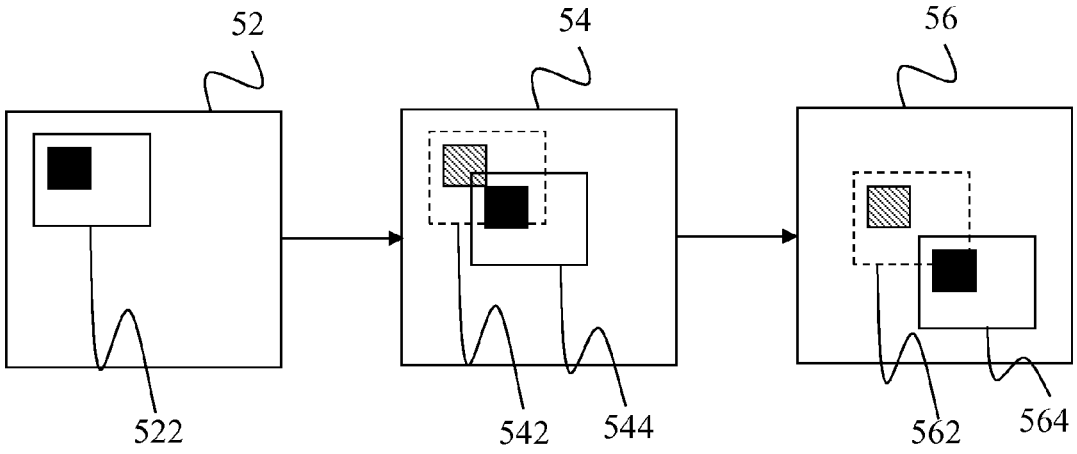


FIG. 4

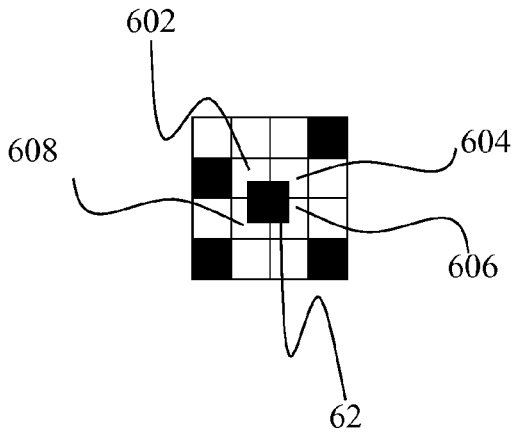


FIG. 5

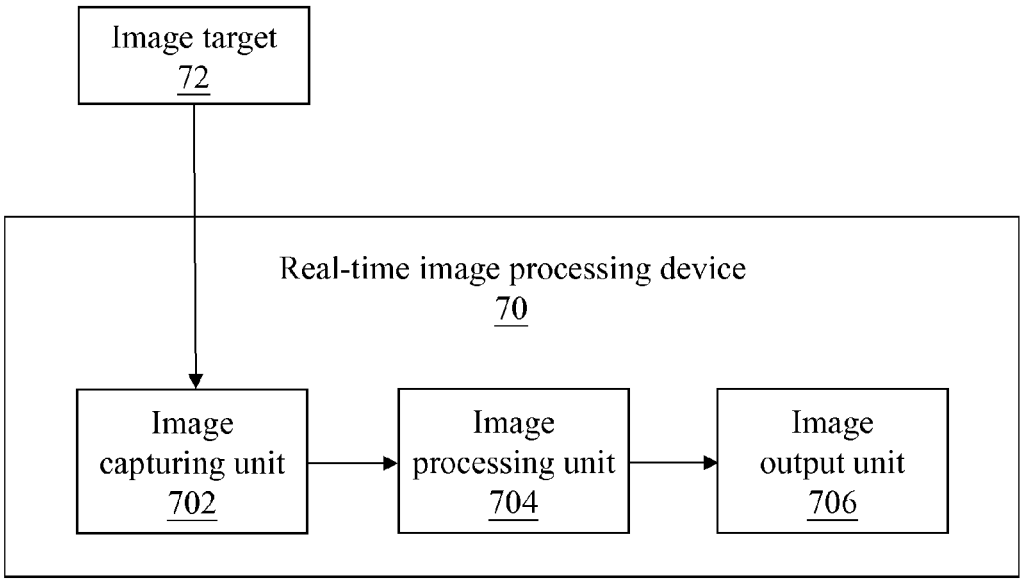


Image target
72
Real-time image processing device
70
Image capturing unit
702
Image processing unit
704
Image output unit
706

FIG. 6

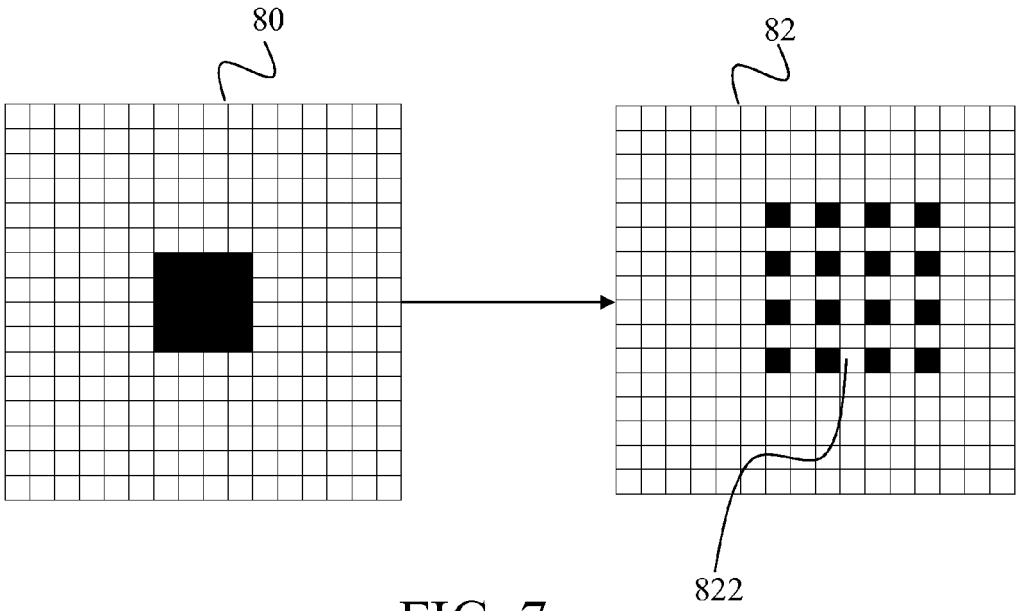

80
82
822

FIG. 7

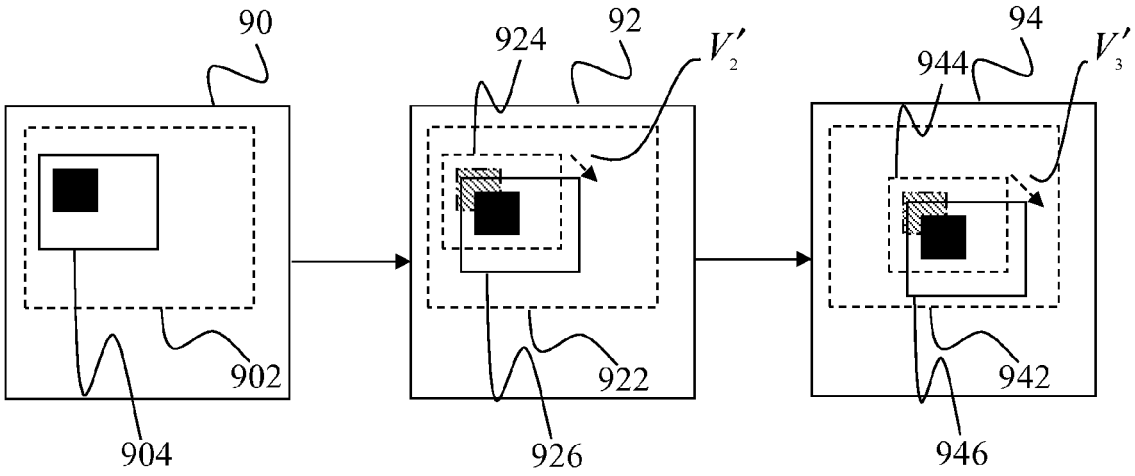


FIG. 8

REAL-TIME IMAGE PROCESSING METHOD AND DEVICE ENHANCING THE RESOLUTION OF SUCCESSIVE IMAGES

CROSS-REFERENCE TO RELATED APPLICATIONS

This non-provisional application claims priority under 35 U.S.C. §119(a) on Patent Application No. 102121252 filed in Taiwan, R.O.C. on Jun. 14, 2013, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

The present invention relates to image processing, particularly to a method and a device of image processing with real-time resolution computation.

BACKGROUND

Recent advances in image processing techniques are primarily focused on improving a general user's visual experience, which is to a large extent affected by image resolution. As for handheld cameras or optical-zoom-capable surveillance cameras, shake, sway, or vibration of the camera body also contributes negatively to the visual experience.

To make an image high-resolution and clear, a digital still camera (DSC) or video camera typically employs optical zoom and digital zoom. Digital zoom takes over from optical zoom when the user demands a magnifying ratio larger than that supported by optical zoom. The camera's built-in processor performs digital zoom to simulate magnification, where some of the pixels are artificially generated and thus deteriorate the image. Magnifying the image without increasing the visual clarity often results in a blurry magnified image. The problem intensifies as the magnifying ratio becomes larger.

Furthermore, the general user is most likely not a professional photographer and is prone to shake the DSC or video camera while using it. Mechanical stabilizers installed on the lens have been developed to cope with this. The side effect, however, is added cost and weight to the camera, in conflict with the user's demand for lightness. In addition, mechanical stabilization does not address the demand for resolution enhancement.

In short, solutions exist for various aspects of image processing, though they are by no means perfect. Digital zoom is limited when it comes to obtain images of high visual clarity, and mechanical stabilization complicates camera design, adding weight and cost despite alleviating shake-induced image blurring.

SUMMARY

In light of the above, the present invention discloses a method and a device of real-time image processing, assisting the user to counter the effect of shake or vibration and enhance the resolution of successive images.

The real-time image processing method of the present invention comprises: capturing a plurality of images, the quantity of the images being three; enhancing a resolution of each of the images to obtain a plurality of high-resolution images, the quantity of the high-resolution images being three; obtaining a plurality of displacement vectors using the high-resolution images, the quantity of the displacement vectors being two; obtaining a superimposed high-resolution image based on the high-resolution images and the displacement vectors; obtaining a compensatory vector based on the displacement vectors; and generating a super-resolution image based on the superimposed high-resolution image and the compensatory vector.

The real-time image processing device of the present invention comprises an image capturing unit and an image processing unit. The image capturing unit is configured to capture a plurality of images, the quantity of the images being three. The image processing unit, coupled with the image capturing unit, is configured to execute a method to obtain a super-resolution image. The method comprises: enhancing a resolution of each of the images to obtain a plurality of high-resolution images, the quantity of the high-resolution images being three; obtaining a plurality of displacement vectors using the high-resolution images, the quantity of the displacement vectors being two; obtaining a superimposed high-resolution image based on the high-resolution images and the displacement vectors; obtaining a compensatory vector based on the displacement vectors; and generating the super-resolution image based on the superimposed high-resolution image and the compensatory vector.

BRIEF DESCRIPTION OF THE DRAWING

The present invention will become more fully understood from the detailed description given herein below and the accompanying drawings which are given by way of illustration only and thus are not limitative of the present invention and wherein:

FIG. **1** is a flowchart of a real-time image processing method, in accordance with an embodiment of the present invention.

FIG. **2** is a block diagram of a real-time image processing device, in accordance with an embodiment of the present invention.

FIG. **3** illustrates an image content being displaced in a real-time image processing method, in accordance with an embodiment of the present invention.

FIG. **4** illustrates the positions of a displaced image content being compared in a real-time image processing method, in accordance with an embodiment of the present invention.

FIG. **5** illustrates a pixel overlaid in a superimposed high-resolution image in a real-time image processing method, in accordance with an embodiment of the present invention.

FIG. **6** illustrates a use case of a real-time image processing device, in accordance with an embodiment of the present invention.

FIG. **7** illustrates the obtainment of a high-resolution image in a real-time image processing method, in accordance with an embodiment of the present invention.

FIG. **8** illustrates displacement vectors being calculated in a real-time image processing method, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details. In other instances, well-known structures and devices are schematically shown in order to simplify the drawings.

The present invention provides a method and a device of real-time image processing. The device may be a DSC, a video camera, a surveillance camera, or any device capable of executing the real-time image processing method. The device

may be used in surveillance or observation while being handheld or mounted on automatic or general moving equipment.

Please refer to FIG. **1**. As shown in the flowchart, in one embodiment the real-time image processing method comprises capturing S**100** three images, enhancing S**110** a resolution of the images to obtain a high-resolution image (hereinafter referred to as HRI) for each of the images, obtaining S**120** two displacement vectors using the HRIs, obtaining S**130** a superimposed HRI based on the HRIs and the displacement vectors, obtaining S**140** a compensatory vector based on the displacement vectors, and generating S**150** a super-resolution image based on the superimposed HRI and the compensatory vector.

Step S**100** is hereby described with regard to FIGS. **2** and **3**. An image capturing unit **302** of the real-time image processing device (**30**) captured the images **42**, **44**, and **46**. The images **42**, **44**, and **46** are of the same view and are successive in time; that is, the images **42**, **44**, and **46** were captured sequentially along the time axis in this embodiment, though not necessarily so in others. The number of images is not limited to three, though it must be at least two. The super-resolution image generated at the end of the real-time image processing method is finer when there are more images captured.

Step S**110** is hereby described with regard to FIGS. **3** and **4**. Each of the images **42**, **44**, and **46** has a plurality of original pixels, and enhancing the resolution of the images **42**, **44**, and **46** may be, but not limited to, inserting blank pixels between the original pixels of each of the images **42**, **44**, and **46**. Inserting blank pixels between the original pixels of the image **42** gives rise to the HRI **52**. Likewise, the HRI **54** is an enhanced image **44**, and the HRI **56** an enhanced image **46**. Please note that the resolution enhancement is not necessarily "square"; that is, the magnifying ratio may not be the same lengthwise and widthwise. The resolution enhancement may be "rectangular." For instance, an image may be magnified three times along one axis (e.g. horizontally) and two times along the other (e.g. vertically). The aspect ratio of a resolution-enhanced image may be, but not limited to, 16:9 or 16:10.

Step S**120** is hereby described with regard to FIG. **4**. An image content **522** was locked on in the HRI **52** and continuously tracked in the HRIs **54** and **56**. The image content **522** changed positions in the HRI **54** to become the image content **544**, its previous position **542** in the HRI **52** indicated by dashed lines. A first displacement vector is obtained by comparing the coordinates. The image content **544** changed positions again in the HRI **56** to become the image content **564**, its previous position **562** in the HRI **54** indicated by dashed lines. A second displacement vector is obtained by comparing the coordinates. Block motion estimation (BME) or optical flow may be, but not necessarily, employed to compare the HRIs **52**, **54**, and **56** to yield the displacement vectors, as detailed later.

Step S**130** is hereby described with regard to FIGS. **4** and **5**. The HRI **54** is reversely adjusted to correspond to the HRI **52** based on the first displacement vector; that is, the image content **544** is moved back to the previous position **542**. Likewise, the HRI **56** is adjusted twice to correspond to the HRI **52** based on the first and second displacement vectors. In other words, the image content **564** is first moved to the previous position **562** and then to the previous position **542**. Superimposing the adjusted HRIs **54** and **56** onto the HRI **52** results in the superimposed HRI, which by nature comprises the original pixels of each of the images **42**, **44**, and **46**, in addition to some residual blank pixels. Some of these original pixels may straddle pixel positions in the superimposed HRI. The overlay pixel **62**, for example, straddles pixel positions **602**, **604**, **606**, and **608**. The brightness values of the neighboring residual blank pixels are calculated based on that of the overlay pixel **62**. Specifically, for a residual blank pixel, its brightness is interpolated from the values of the surrounding original pixels. Saturation is calculated in addition to brightness for color images.

In step S**140**, the compensatory vector is obtained using the first and second displacement vectors. In one embodiment, the compensatory vector is computed based on the following simultaneous equations:

$$\tilde{V}_n = \frac{\tilde{V}_{n-1} W_{n-1} + V_n W_n}{W_{n-1} + W_n}$$

$$\tilde{V}_1 = (0, 0)$$

$$V_n = \sum_{i=k}^{n} V'_i$$

where i, n, and k are natural numbers, V'_i is the displacement vector of an i-th image relative to an (i−1)-th image, $\tilde{V}_i$ is the compensatory vector of the i-th image, and W_{n-1} and W_n are real-number weights. k is determined using sum of absolute differences (SAD); that is,

$$SAD(A, B) = \sum_{(x,y)\in A} |A(x, y) - B(x, y)|$$

where A(x,y) represents a pixel value corresponding to a pixel coordinate set or coordinates (x,y) in an image A, and B(x,y) represents a pixel value corresponding to the pixel coordinates (x,y) in an image B. k is set to j if SAD (a j-th image, a (j−1)-th image) is greater than a real-number threshold value, j being a natural number; otherwise k is set to 1.

It is assumed that the image **42** was the first image captured after the real-time image processing device **30** initiated image capturing. V'_1, therefore, does not exist, and $\tilde{V}_1=(0,0)$. Let $\tilde{V}_1$ take no weight (i.e., let $W_1=0$). Let V'_2 be the first displacement vector and V'_3 the second. $\tilde{V}_2$, the compensatory vector of the (second) image **44**, is then simply V_2 according to the simultaneous equations above with $\tilde{V}_1=(0,0)$ and $W_1=0$, regardless of the value of W_2. The objective of step S**140** is to obtain $\tilde{V}_3$, the compensatory vector of the (third) image **46**.

For n=3 and beyond, W_{n-1} and W_n are constants W_a and W_b, respectively. W_a and W_b may be identical or different. To make the result of vector compensation more akin to the latest situation, let W_b be greater than W_a, e.g. $W_b=0.7$ and $W_a=0.3$. To make the result of vector compensation more stable, let W_b be smaller than W_a, e.g. $W_b=0.3$ and $W_a=0.7$. The weights can be user-defined.

If the result of the above SAD computation is greater than a real-number threshold value, the image sequence is reset, the next images becoming the first, the second, and so on, to calculate the compensatory vectors as described above.

In step S**150**, the super-resolution image is generated by displacing whole contents in the superimposed HRI (from step S**130**) using the compensatory vector (from step S**140**). The super-resolution image is then output.

In the current embodiment, the image **42** is not output since there is no prior image for superimposition. The image **44** is not output, either, because there is only one image **42** available for superimposition.

In another embodiment, the image **42** can be digitally magnified (e.g. by interpolation) and output, and the image **44** is superimposed onto the image **42** and output. The general user may therefore have a smoother visual experience, despite that the first two output images are of lower quality.

Please refer to FIG. **2**. As shown in the block diagram, the real-time image processing device **30** comprises the image capturing unit **302**, an image processing unit **304**, and an image output unit **306**. In the current embodiment, the image capturing unit **302** sends the images **42**, **44**, and **46** to the image processing unit **304**, which in turn sends the super-resolution image to the image output unit **306**.

The image capturing unit **302**, configured to capture images and convert them into digital data, may be a photon sensor of a DSC, a digital video camera, or a surveillance camera system. In particular, the image capturing unit **302** may be a charge-coupled device (CCD) or based on complementary metal-oxide-semiconductor (CMOS).

The image processing unit **304** is configured to execute at least part of the real-time image processing method, which is an amalgam of the procedures of the invention for obtaining the super-resolution image and stabilizing the HRIs **52**, **54**, and **56**. The image processing unit **304** may be a processor capable of performing image processing, such as a central processing unit (CPU) or an image processor of a DSC or digital video camera. Per user request, the image processing unit **304** optionally performs image compression to generate, say, JPEG or GIF files, after the real-time image processing method is completed.

The image output unit **306** outputs the super-resolution image acquired by the image processing unit **304** to a target device. The target device may be storage equipment connected to the image output unit **306**, a memory card or hard disk drive for instance, or it may be remote storage equipment connected through a wired or wireless network. A wired connection may be physical cables or Universal Serial Bus (USB) links; a wireless connection may be based on Wi-Fi or Bluetooth.

Please refer to FIG. **6**. The block diagram shows the real-time image processing device (**70**, described as **20** in FIG. **2**) and an image target **72**, which is what the user is photographing.

Suppose that the real-time image processing device **70** is a surveillance camera in an airport. Given the high security concerns of the airport, the camera is by necessity capable of optical zoom with large magnifying ratios, a side effect being that the vibration of the camera body due to natural causes is also magnified and observable on the captured images. The present invention can counter this side effect and generate HRIs. The image target **72** is contained in the interior of the airport. The image capturing unit **702** comprises a lens with optical zoom and captures a first image, a second image, and a third image with regard to the image target **72**. The images are sent to the image processing unit **704**, which obtains a first HRI, a second HRI, and a third HRI by inserting blank pixels between original ones of the images, based on a default or dynamically set magnifying ratio.

The first and second HRIs are compared through optical flow to yield a first displacement vector V'_2. Likewise, the second and third HRIs are compared to yield a second displacement vector V'_3. Using V'_2 and V'_3 as reference, at least part of the HRIs are superimposed with regard to the image target **72**, which appears throughout the images. A superimposed HRI is thus obtained with residual blank pixels accounted for by interpolation as formerly described. Substituting V'_2 and V'_3 into the aforesaid equations gives a compensatory vector $\tilde{V}_3$ of the third HRI. Displacement of contents is then performed on the superimposed HRI based on $\tilde{V}_3$, resulting in a super-resolution image. A later part of this disclosure elaborates on the above computation. The super-resolution image is sent to the image output unit **706**, which may be a closed-circuit television (CCTV) in a security control room.

Besides optical flow, there are other known algorithms by which the displacement vectors can be obtained.

In another example, suppose that the real-time image processing device **70** is a handheld DSC. Photographing in motion often leads to the camera being shaken. The present invention can counter the shake-induced blurring and generate HRIs. The target **72** is for example an animal, a human-being, or an inanimate object. The image capturing unit **702** comprises a lens with optical zoom and captures a first image, a second image, and a third image with regard to the image target **72**. The images are sent to the image processing unit **704**, which obtains a first HRI, a second HRI, and a third HRI by inserting blank pixels between original ones of the images, based on a default or dynamically set magnifying ratio.

The first and second HRIs are compared through pixel-value differencing to yield a first displacement vector V'_2. Likewise, the second and third HRIs are compared to yield a second displacement vector V'_3. Using V'_2 and V'_3 as reference, at least part of the HRIs are superimposed with regard to the image target **72**, which appears throughout the images. A superimposed HRI is thus obtained with residual blank pixels accounted for by interpolation as formerly described. Substituting V'_2 and V'_3 into the aforesaid equations gives a compensatory vector $\tilde{V}_3$ of the third HRI. Displacement of contents is then performed on the superimposed HRI based on $\tilde{V}_3$, resulting in a super-resolution image. A later part of this disclosure elaborates on the above computation. The super-resolution image is sent to the image output unit **706**, which may be a view-finding liquid crystal display (LCD) of the DSC.

Besides pixel-value differencing, there are other known algorithms by which the displacement vectors can be obtained.

Please refer to FIG. **7**, which depicts an original image **80** and a part **82** of a HRI. As shown in the diagram, some of the pixels of the original image **80** form a block of color. The HRI is obtained by magnifying the original image **80** four times. Through a scaling algorithm, the block of color is filled with several blank pixels **822** in the part **82** of the HRI.

Please refer to FIG. **8**, which shows surveillance screens four-time magnified to become HRIs **90**, **92**, and **94**, as formerly described. The HRIs **90**, **92**, and **94** are captured sequentially along the time axis; that is, the HRI **90** is obtained earlier than the HRI **92**, and the HRI **92** is obtained earlier than the HRI **94**. In this example, displacement vectors are calculated by BME, which in principle is detecting pixels of certain regions in the screens, or locking on a plurality of blocks **902**, **922**, and **942**.

The first block **902** is locked on in the HRI **90**, and an image content **904** in the block **902** is continuously tracked in the HRIs **92** and **94**. The image content **904** changed positions in the HRI **92** to become the image content **926** in the block **922**, its previous position **924** in the HRI **90** indicated by dashed lines. A first displacement vector V'_2 is obtained as (3,3) by comparing the coordinates. The image content **926** changed positions again in the HRI **94** to become the image content **946** in the block **942**, its previous position **944** in the HRI **92** indicated by dashed lines. A second displacement vector V'_3 is obtained as (5,5) by comparing the coordinates. Please note that the calculated displacement vectors may have integral or fractional components.

The HRI **92** is reversely adjusted to correspond to the HRI **90** based on V'_2; that is, the image content **926** is moved back to the previous position **924**. Likewise, the HRI **94** is adjusted twice to correspond to the HRI **90** based on V'_2 and V'_3. In other words, the image content **946** is first moved to the previous position **944** and then to the previous position **924**. Superimposing the adjusted HRIs **92** and **94** onto the HRI **90** results in a superimposed HRI, which by nature comprises the original pixels of the surveillance screens, in addition to some residual blank pixels. The values of the residual blank pixels are calculated based on the original pixels.

A compensatory vector is computed based on the aforesaid equations. In this example, $\tilde{V}_1=(0,0)$, $V'_2=V_2=\tilde{V}_2=(3,3)$, $V'_3=(5,5)$, $V_3=(8,8)$. Let $W_a=W_b=0.5$, then

$$\tilde{V}_3 = \frac{\tilde{V}_2 W_a + V_3 W_b}{W_a + W_b} = \frac{(3,3)\cdot 0.5 + (8,8)\cdot 0.5}{0.5+0.5} = (5.5, 5.5)$$

where $\tilde{V}_3$ is the compensatory vector of the HRI **94**. Displacement of contents by (−5.5,−5.5) is then performed on the superimposed HRI, resulting in a super-resolution image. Please note that such displacement involves interpolation since the compensatory vector consists of fractions.

BME or optical flow may be employed to yield V'_2 and V'_3. BME may be, but not necessarily, implemented with pixel-value differencing.

To summarize the present invention, the real-time image processing method and device, by enhancing image resolution, outputs and stabilizes a super-resolution image without the general user experiencing latency. Implemented in an image processor, the present invention does not incur additional hardware cost for DSCs, digital video cameras, or surveillance systems. The two procedures of outputting and stabilization, no longer separately executed, are fused to reduce the temporal cost of image processing.

The foregoing description has been presented for purposes of illustration. It is not exhaustive and does not limit the invention to the precise forms or embodiments disclosed. Modifications and adaptations will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed embodiments of the invention. It is intended, therefore, that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims and their full scope of equivalents.

What is claimed is:

1. A real-time image processing method comprising:

capturing a plurality of images, a quantity of the plurality of images being three;

enhancing a resolution of each of the plurality of images to obtain a plurality of high-resolution images, a quantity of the plurality of high-resolution images being three;

obtaining a plurality of displacement vectors using the plurality of high-resolution images, a quantity of the plurality of displacement vectors being two;

obtaining a superimposed high-resolution image based on the plurality of high-resolution images and the plurality of displacement vectors;

obtaining a compensatory vector based on the plurality of displacement vectors; and

generating a super-resolution image based on the superimposed high-resolution image and the compensatory vector.

2. The real-time image processing method of claim **1**, wherein each of the plurality of images comprises a plurality of original pixels, and the enhancing the resolution of each of the plurality of images is inserting a plurality of blank pixels between the original pixels of each of the plurality of images based on a magnifying ratio.

3. The real-time image processing method of claim **1**, wherein the obtaining the plurality of displacement vectors comprises:

computing the plurality of displacement vectors using block motion estimation or optical flow.

4. The real-time image processing method of claim **1**, wherein each of the plurality of images comprises a plurality of original pixels, and the obtaining the superimposed high-resolution image comprises:

superimposing the plurality of high-resolution images based on the plurality of displacement vectors to obtain the superimposed high-resolution image, the superimposed high-resolution image comprising the original pixels of each of the plurality of images and a plurality of residual blank pixels; and

obtaining a plurality of pixel values of the residual blank pixels based on the original pixels of each of the plurality of images.

5. The real-time image processing method of claim **1**, wherein the obtaining the compensatory vector is based on a system of equations, the system of equations being:

$$\tilde{V}_n = \frac{\tilde{V}_{n-1} W_{n-1} + V_n W_n}{W_{n-1} + W_n}$$

$$\tilde{V}_1 = (0, 0)$$

$$V_n = \sum_{i=k}^{n} V'_i$$

wherein i, n, and k are natural numbers, V'_i is an i-th displacement vector of an i-th image relative to an (i−1)-th image, $\tilde{V}_i$ is an i-th compensatory vector of the i-th image, and W_{n-1} and W_n are real-number weights;

wherein the i-th image and the (i−1)-th image are of the plurality of images, the i-th displacement vector is of the plurality of displacement vectors;

wherein W_{n-1} is a constant W_a and W_n is a constant W_b for n≥3.

6. The real-time image processing method of claim **5**, wherein k is determined by an expression of sum of absolute differences (SAD), the expression being:

$$SAD(A, B) = \sum_{(x,y)\in A} |A(x, y) - B(x, y)|$$

wherein A(x,y) represents a pixel value corresponding to a pixel coordinate set (x,y) in an image A, and B(x,y) represents a pixel value corresponding to a pixel coordinate (x,y) in an image B;

wherein k is set to j if SAD (a j-th image, a (j−1)-th image) is greater than a real-number threshold value, j being a natural number;

wherein k is set to 1 if SAD (the j-th image, the (j−1)-th image) is not greater than the real-number threshold value;

wherein the j-th image and the (j−1)-th image are of the plurality of images.

7. A real-time image processing device comprising:

an image capturing unit configured to capture a plurality of images, a quantity of the plurality of images being three; and

an image processing unit coupled with the image capturing unit and configured to enhance a resolution of each of the plurality of images to obtain a plurality of high-resolution images, a quantity of the plurality of high-resolution images being three, to obtain a plurality of displacement vectors using the plurality of high-resolution images, a quantity of the plurality of displacement vectors being two, to obtain a superimposed high-resolution image based on the plurality of high-resolution images and the plurality of displacement vectors, to obtain a compensatory vector based on the plurality of displacement vectors, and to generate a super-resolution image based on the superimposed high-resolution image and the compensatory vector.

8. The real-time image processing device of claim 7, further comprising an image output unit coupled with the image processing unit and configured to output the super-resolution image.

9. The real-time image processing device of claim 7, wherein the image processing unit is further configured to perform image compression.

10. The real-time image processing device of claim 7, wherein the image capturing unit is capable of optical zoom.

11. The real-time image processing device of claim 7, wherein the compensatory vector is obtained based on a plurality of equations, the plurality of equations being:

$$\tilde{V}_n = \frac{\tilde{V}_{n-1} W_{n-1} + V_n W_n}{W_{n-1} + W_n}$$

$$\tilde{V}_1 = (0, 0)$$

-continued

$$V_n = \sum_{i=k}^{n} V_i'$$

wherein i, n, and k are natural numbers, V'_i is an i-th displacement vector of an i-th image relative to an (i−1)-th image, $\tilde{V}_i$ is an i-th compensatory vector of the i-th image, and W_{n-1} and W_n are real-number weights;

wherein the i-th image and the (i−1)-th image are of the plurality of images, the i-th displacement vector is of the plurality of displacement vectors;

wherein W_{n-1} is a constant W_a and W_n is a constant W_b for n≥3.

12. The real-time image processing device of claim 11, wherein k is determined by an expression of sum of absolute differences (SAD), the expression being:

$$SAD(A, B) = \sum_{(x,y)\in A} |A(x, y) - B(x, y)|$$

wherein A(x,y) represents a pixel value corresponding to a pixel coordinate set (x,y) in an image A, and B(x,y) represents a pixel value corresponding to a pixel coordinate set (x,y) in an image B;

wherein k is set to j if SAD (a j-th image, a (j−1)-th image) is greater than a real-number threshold value, j being a natural number;

wherein k is set to 1 if SAD (the j-th image, the (j−1)-th image) is not greater than the real-number threshold value;

wherein the j-th image and the (j−1)-th image are of the plurality of images.

* * * * *